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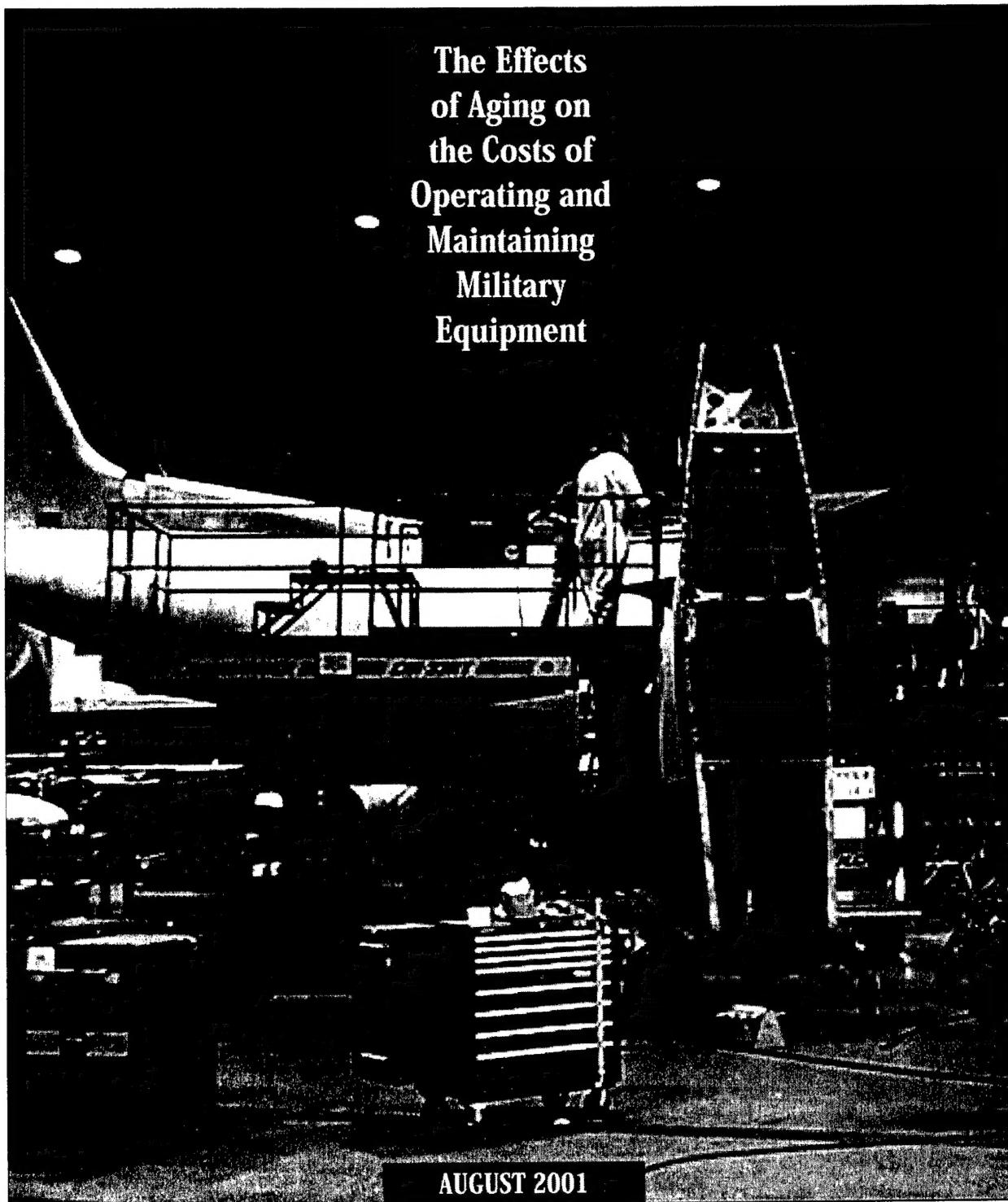
CONGRESS OF THE UNITED STATES
CONGRESSIONAL BUDGET OFFICE

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CBO
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20010918 105

The Effects
of Aging on
the Costs of
Operating and
Maintaining
Military
Equipment



AUGUST 2001

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A . Report Title : The Effects of Aging on the Costs of Operating and Maintaining Military Equipment

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**C. Report's Point of Contact: (Congress of the United States
Congressional Budget Office Washington DC 20037)**

D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

**F. The foregoing information was compiled and provided by:
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AQU01-12-2260

The Effects of Aging
on the Costs of Operating and
Maintaining Military Equipment

The Congress of the United States
Congressional Budget Office

NOTES

Unless otherwise noted, all dollar amounts referred to in this paper are in constant fiscal year 2000 dollars, and all years are fiscal years.

Unless otherwise indicated, all references to Navy aircraft also include Marine Corps and Navy Reserve aircraft.

The cover photo depicts a C-130 undergoing extensive depot maintenance at Hill Air Force Base, Utah.

PREFACE

Many military leaders and defense analysts believe that increases in the costs of operating and maintaining aging military equipment have created a budgetary crisis in the Department of Defense. Yet no one has provided clear and comprehensive information on those costs. Nevertheless, the effects of age are likely to become increasingly important because, even with planned purchases of new equipment, most major military weapon systems will increase in average age during the coming decade.

The Senate Budget Committee asked the Congressional Budget Office (CBO) to analyze defense spending on operation and maintenance (O&M). As part of CBO's response to that request, this paper examines the extent to which aging equipment has contributed to the overall growth in O&M spending, reviews the available literature on the effects of aging, and briefly describes some approaches to address the costs associated with aging equipment.

Gregory T. Kiley of CBO's National Security Division prepared the report under the supervision of Christopher Jehn and Deborah Clay-Mendez. Eric J. Labs thoroughly reviewed the manuscript before publication. Arlene Holen, Jo Ann Vines, Robert McClelland, and Zachary Selden of CBO and Thomas McNaugher of the RAND Corporation provided helpful comments. Billy Trimble of CBO and Mike Aguilar (formerly of CBO) provided valuable research assistance.

John Skeen edited the manuscript, and Christine Bogusz proofread it. Cindy Cleveland prepared it for publication. Lenny Skutnik produced the printed copies, and Annette Kalicki prepared the electronic versions for CBO's Web site (www.cbo.gov).



Dan L. Crippen
Director

August 2001

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SUMMARY AND INTRODUCTION

Many defense experts and senior military leaders believe that the U.S. military is in a “defense spending death spiral” that threatens to severely reduce the effectiveness of the nation’s armed forces. According to one interpretation, decisions in the 1990s to reduce purchases of new equipment left the military with aging fleets of ships, aircraft, and armored vehicles that are increasingly expensive to maintain. This situation creates a cycle in which more funds are spent maintaining older equipment at the expense of new purchases, which in turn leads to still older equipment and higher maintenance costs.¹ Currently, about 37 percent of the Department of Defense’s (DoD’s) budget pays for the day-to-day costs of operation and maintenance (O&M), and 26 percent goes for the salaries and benefits of military personnel. The remaining 37 percent goes toward researching, developing, and purchasing new equipment; building new facilities; and paying for other expenses such as family housing (see Figure 1).

The argument that older equipment is more expensive to operate and maintain is intuitively appealing. And, as the average ages of all types of weapon systems rise in the coming decade, the connection between the age of equipment and O&M costs will become increasingly important. To help explain that connection, the Congressional Budget Office (CBO) addressed the following two questions:

- o Do aging equipment and the associated costs of operating and maintaining it explain trends in total spending on O&M?
- o What can be learned from existing studies and data about the relationship between the age of equipment and the costs of operating and maintaining that equipment?

CBO’s analysis of that first question, presented in detail in the next section of this paper, finds no evidence to support the services’ contention that spending on O&M for aging equipment has driven total O&M spending. Today, only about 20 percent of total O&M spending is devoted to equipment. And the fraction of O&M funds spent operating and maintaining equipment appears to be declining. Moreover, the services’ statements about growth in equipment costs are sometimes based on selective data, including anecdotal or partial data. According to CBO’s review of

1. Jacques S. Gansler, former Under Secretary of Defense for Acquisition & Technology, is often credited with creating the term “defense spending death spiral” to describe the effect that aging equipment has had on the defense budget. Similar views have been expressed by many leaders in each of the military services. However, some defense analysts have used the phrase to refer to a broader problem of declining rates of modernization, aging equipment, inadequate readiness, and diminishing morale. See, for example, Donald E. Vandergriff, ed., *Spirit, Blood, and Treasure: The American Cost of Battle in the 21st Century* (Novato, California: Presidio Press, 2001), available at www.belisarius.com. This paper examines the narrower assertion that aging equipment is the root cause of higher operation and maintenance costs.

spending on maintenance overhauls for weapon systems and spending per operating hour, O&M spending for most types of equipment has not risen in the past decade. Additionally, the average ages of many types of equipment, such as ships and tanks, are not much greater than they were 20 years ago.

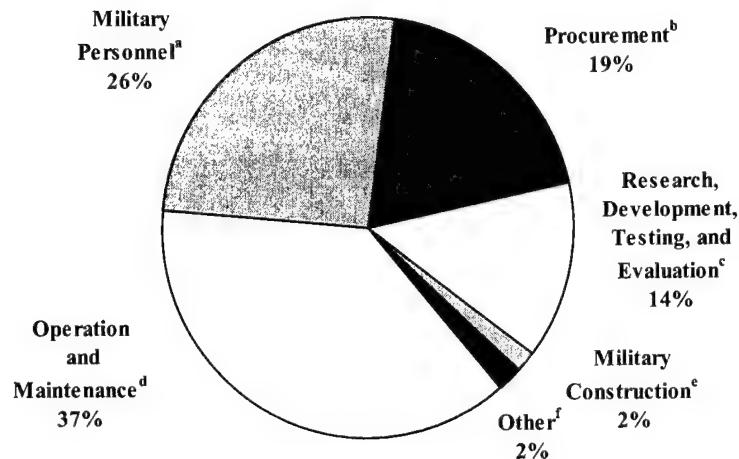
Total O&M spending is a broad category, comprising much more than spending on equipment. It includes spending on health care, management (by, for example, the Office of the Secretary of Defense, the Joint Staff, and service staffs at headquarters), environmental programs (for example, pollution prevention and environmental restoration), real property maintenance (for example, the maintenance and repair of buildings, roadways, and runways), base operating support (for example, child care and family support), and communications (for example, telephone systems and computer infrastructure). Thus, the fact that aging equipment does not appear to be driving total O&M spending does not rule out the possibility that the costs of operating and maintaining equipment increase with the age of that equipment.

CBO's analysis of the relationship between equipment costs and age, which focused on Air Force and Navy aircraft and is presented in the third section of this paper, indicates that aircraft do become more costly to maintain as they age. CBO estimates that spending on O&M for aircraft increases by 1 percent to 3 percent for every additional year of age, after adjusting for inflation. (For the Air Force, those figures could translate into an increase of \$80 million to \$230 million per year in an annual O&M budget of approximately \$22 billion. For the Navy, spending could increase by \$40 million to \$130 million per year in an annual O&M budget of approximately \$23 billion.) Furthermore, in the future, as some systems reach unprecedented ages, the rate of cost growth could accelerate and increase total spending on O&M.

One implication of CBO's analysis is that DoD and defense analysts need to look at factors other than equipment's operation or its aging to explain trends in total O&M spending. A comprehensive budget exhibit that would provide a breakout of O&M spending on equipment—covering the costs of fuel, spare parts, and depot maintenance for all of the services—would aid the Congress and DoD officials in understanding the role that equipment costs play in driving total O&M spending.²

2. The Office of the Secretary of Defense publishes the *Operation and Maintenance Overview* each year, which breaks out O&M spending in various ways. However, none of those breakouts can be aggregated to create an estimate of total O&M spending on equipment. DoD's financial management regulations require the department and each service to prepare additional backup materials on equipment costs (for different types of aircraft and different types of ships, those materials are Exhibit Numbers OP-20A through OP-20E and Exhibit Numbers OP-40 and OP-41, respectively). But those exhibits are not presented to the Congress, and the Army has no similar exhibit for O&M costs of vehicles. Aggregating those exhibits and including spending on fuel, spare parts, and depot maintenance for Army vehicles as part of the Office of the Secretary of Defense's *Operation and Maintenance Overview* would create a visible DoD-wide exhibit of O&M costs for equipment.

FIGURE 1. MAKEUP OF THE DEPARTMENT OF DEFENSE'S BUDGET,
FISCAL YEAR 2000



SOURCE: Congressional Budget Office based on data from the Department of Defense.

- a. "Military Personnel" includes spending on salaries and benefits.
- b. "Procurement" includes purchases of new equipment and paying for major modifications of existing systems.
- c. "Research, Development, Testing, and Evaluation" covers the costs of developing and testing new systems and subsystems.
- d. "Operation and Maintenance" (O&M) includes spending on fuel, spare parts, and overhauls of military equipment. O&M also includes spending on such items as health care, management (by, for example, the Office of the Secretary of Defense, the Joint Staff, and service staffs at headquarters), environmental programs (for example, pollution prevention and environmental restoration), real property maintenance (for example, the maintenance and repair of buildings, roadways, and runways), base operating support (for example, child care and family support), and communications (for example, telephone systems and computer infrastructure).
- e. "Military Construction" pays for building new facilities and support structures for military installations.
- f. "Other" includes spending on family housing and management of working capital revolving funds.

CBO also finds that efforts to identify the effects of aging on the costs of operating and maintaining equipment are hampered by the fact that there are few sources of data on those costs for individual pieces of equipment. That lack of information hinders attempts to make cost-effective decisions about maintaining current systems, rebuilding them to "like-new" condition, or buying new systems. Data collection efforts that track costs for selected pieces of equipment over time could be one solution; in the future, such efforts could be required as a part of testing programs aimed at reducing O&M costs for weapon systems.

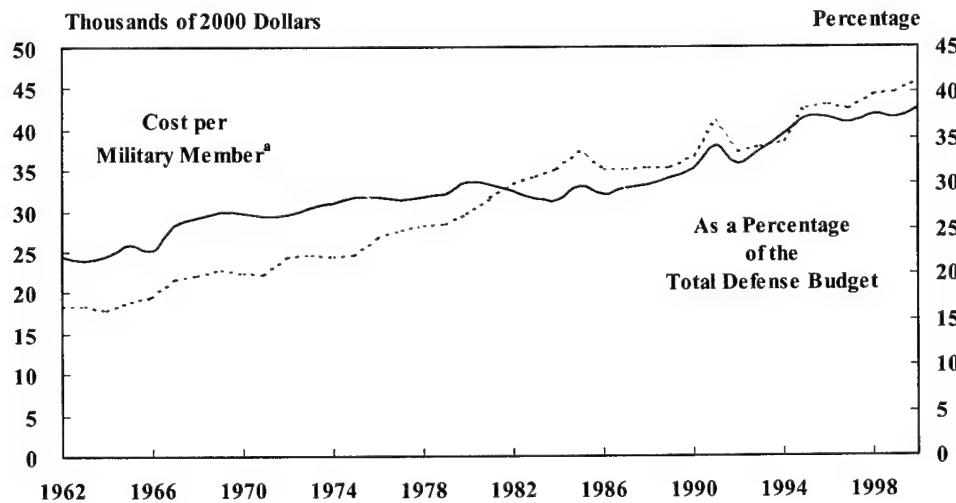
Equipment's age can affect readiness as well as maintenance costs. However, this analysis looks only at the relationship between equipment's age and actual spending on that equipment. As a result, CBO's finding that spending on equipment

is not driving total O&M spending should not be interpreted as an indication that current spending on equipment is adequate or does not need to increase.

ANALYSIS OF SPENDING ON OPERATION AND MAINTENANCE AND OF THE AVERAGE AGES OF WEAPON SYSTEMS

Many of those concerned about the effects of aging systems on operation and maintenance costs point to recent growth in spending on O&M relative to the number of military personnel and to the department's total budget (see Figure 2). They cite the costs associated with aging weapon systems as a major factor behind that growth. Although aging equipment may have contributed to increased spending on O&M per military member, there are many other possible explanations for the rise, such as medical costs, which are also included in O&M spending, or decreases in the number of personnel and the introduction of labor-saving technology. In addition, regardless of what is happening to the costs of operating and maintaining equipment, the share

FIGURE 2. OPERATION AND MAINTENANCE SPENDING PER MILITARY MEMBER
AND AS A PERCENTAGE OF THE TOTAL DEFENSE BUDGET, 1962-2000



SOURCE: Congressional Budget Office based on data from the Department of Defense.

a. Includes both active-duty military and selected reserve members.

of DoD's budget allocated to O&M may rise or fall depending on decisions about other defense policies and programs for personnel; procurement; research, development, testing, and evaluation; and military construction.

This review by the Congressional Budget Office has identified three reasons why aging equipment cannot explain the observed trends in total O&M spending.

- o First, O&M dollars that are spent directly on operating and maintaining military equipment—to pay for fuel, purchase or repair parts, and overhaul weapon systems at depots—account for a relatively modest share (about one-fifth) of total O&M expenditures today. By itself, that share is not large enough to account for the observed trends in total O&M spending.
- o Second, O&M spending associated with deployable military units—a category that includes most equipment-related costs—has steadily declined as a share of total spending on O&M since 1985. The most rapid growth in O&M spending relative to the size of the forces has been for items other than deployable units, including such diverse areas as health care and environmental programs.
- o Third, the average ages of certain classes of equipment—including Navy ships and Army armored vehicles—are no higher than they were 10 or 20 years ago. And, although the average ages of Navy and Air Force aircraft did increase over the past two decades, after adjustments for inflation the aggregate O&M spending per operating hour or per aircraft did not consistently grow.

The Magnitude of Spending on O&M for Equipment

O&M spending for equipment includes the costs of the parts and fuel used by military units, as well as the costs incurred in maintaining equipment at large centralized maintenance facilities called depots. Parts include what are termed “consumables,” such as washers, filters, and gaskets, and “depot-level reparables” (DLRs), such as spare parts, avionics, and engine components. Major overhauls at depots, which are public (DoD) or private (contractor) repair facilities, involve major inspection and repair of weapon systems; the costs for them include both materiel and civilian labor costs. The costs of military personnel engaged in operating and maintaining the equipment are not included in O&M spending because those costs are not covered by the O&M appropriation.

By itself, spending on equipment (as described in Table 1) is not large enough to account for the observed 2 percent to 3 percent annual increase in O&M spending

per service member. The amount spent to operate and maintain equipment in 1999 was 20 percent of the total O&M budget—\$20.3 billion out of \$102.7 billion (in current dollars). Given the current share of spending on O&M, an annual increase of 13 percent would be needed to cause a 2 percent to 3 percent annual increase in the total O&M budget relative to the number of military personnel.

The other 80 percent of spending on O&M is spread out among activities not directly associated with equipment. For example, spending for health care, headquarters management, environmental cleanup, the upkeep of base facilities, base operating support, and communications accounts for more than twice as much of the spending on O&M as the direct cost of operating and maintaining equipment does.

TABLE 1. DISTRIBUTION OF SPENDING ON OPERATION AND MAINTENANCE,
FISCAL YEAR 1999 (In current dollars)

Funding Category	In Billions of Dollars	As a Percentage of O&M Budget
Purchase or Repair of Parts ^a	9.6	9
Fuel ^a	3.6	4
Major Overhauls at Depots ^b	<u>7.1</u>	<u>7</u>
Subtotal, spending on O&M related to military equipment	20.3	20
All Other Spending on O&M ^c	<u>82.4</u>	<u>80</u>
Total Spending on O&M ^d	102.7	100

SOURCE: Congressional Budget Office based on data from the Department of Defense.

NOTE: O&M = operation and maintenance.

- a. From the services' databases (see Box 1). "Purchase or repair of parts" includes actual expenditures on consumables, such as washers, filters, and gaskets, and "depot-level reparables" (DLRs), such as spare parts, avionics, and engine components. Those costs, combined with ones for fuel, are what are often referred to as "steaming-hour," "flying-hour," or "tank-mile" costs.
- b. From the services' budget exhibits. Includes spending on the inspection, maintenance, and repair of military equipment—excluding DLRs—at large public (Department of Defense) and private (contractor) depots.
- c. Includes spending on health care, management by headquarters, environmental programs, real property maintenance, base operating support, and communications.
- d. From the Department of Defense's *National Defense Budget Estimates for FY2001*.

Trends in Spending on O&M

The data used to construct the one-year snapshot of spending on O&M shown in Table 1 are not available from the services for earlier years because of multiple accounting changes and modifications to databases (see Box 1). Moreover, the most continuously maintained data on DoD's spending—information in the Historical Future Years Defense Program (FYDP), compiled by the Office of the Secretary of Defense (see Box 2)—do not explicitly track O&M costs of equipment. However, the FYDP does separate spending on O&M into mission-related and mission-support spending. Thus, changes in mission-related O&M spending may indicate how spending on O&M for equipment has changed over time. Mission-related O&M spending, which can be thought of as spending to train and operate the combat forces that may be deployed in a conflict, includes most equipment-related spending.

FYDP data provide no evidence that spending on equipment has increased in recent years. O&M spending on deployable units—a category that includes most O&M equipment-related costs along with other costs—has fallen faster than total spending on O&M since 1985 (see Figure 3). Indeed, an increasing portion of total O&M spending is not equipment-related. For example, despite about a 30 percent reduction in the size of the armed forces from 1991 to 1999, annual O&M spending on health care remained the same, at just over \$10 billion. Furthermore, O&M spending on environmental programs increased by 50 percent over the same period, rising from \$3 billion to \$4.4 billion annually.

In the future, the Congress and the Office of the Secretary of Defense might find it useful to have information on those O&M costs that are specifically for equipment.³ DoD could provide to the Congress a summary of such costs—including those for fuel, spare parts, and depot maintenance—in its annual O&M budget exhibits. Currently, as required by the department's financial management regulations, the department and each service prepare backup materials on O&M costs for different types of aircraft and different types of ships.⁴ However, those exhibits are not presented to the Congress, and no similar exhibit exists on the O&M costs of Army vehicles. Aggregating the existing exhibits and including spending on fuel, spare parts, and depot maintenance for Army vehicles as part of the Office of the Secretary of Defense's annual *Operation and Maintenance Overview* would create a visible DoD-wide exhibit of O&M costs for equipment.

3. A recent report by the General Accounting Office recommended to the Secretary of Defense that similar information on the total funding for spare parts routinely be provided to the Congress. See General Accounting Office, *Information on the Use of Spare Parts Funding Is Lacking*, GAO-01-472 (June 2001).
4. DoD's financial management regulations identify those background exhibits as Exhibit Numbers OP-20A through OP-20E for aircraft operating costs and Exhibit Numbers OP-40 and OP-41 for ship operating costs.

BOX 1.
THE ARMED SERVICES' DATABASES
OF OPERATION AND MAINTENANCE COSTS

Each service maintains a repository of operation and support cost data—spending on operation and maintenance (O&M) plus spending on military personnel—for its weapon systems. The Navy's is called Visibility and Management of Operating and Support Costs (VAMOSC); the Army's, Operating and Support Management Information System (OSMIS); and the Air Force's, Air Force Total Ownership Costs (AFTOC). Those databases are compiled from hundreds of other databases that collect cost data as well as data on operations—on the hours flown or sailed, the miles driven, or the equipment in inventory.

The services' data suffer from some weaknesses, many of which were identified in a 1995 UNISYS study.¹ Those weaknesses include the following: the services' data are not reported in a consistent way over a long time period because of accounting changes and modifications of databases; some costs are not tracked to specific types of equipment but are aggregated and then allocated to equipment on the basis of uncertain assumptions; and some costs are not captured, such as those for maintenance and repairs contracted to the private sector directly by military units.

Despite their weaknesses, the Air Force's data go back to 1996, the Army's to 1993, and the Navy's to 1984 for ships and 1986 for aircraft. Those databases are the best available sources of detailed information on the costs of operating and maintaining military equipment. Additionally, each service is improving its database systems to make costs more visible and analyzable.

1. UNISYS, *Visibility and Management of Operations and Support Costs (VAMOSC): Documentation of Existing VAMOSC Systems Contract MDA903-93-D-0013* (prepared for the Office of the Secretary of Defense, February 28, 1995).

Average Ages of and Spending on O&M for Ships, Aircraft, and Army Equipment

The argument that aging equipment accounts for increases in aggregate O&M spending (rather than increased costs for specific systems) relies on two assumptions: that the average age of equipment has increased and that spending on O&M for equipment has risen.⁵ However, CBO's analysis shows that ships, tanks, and tactical wheeled vehicles have not increased in average age over the past two decades; aircraft (including helicopters) are the only types of weapon systems that have increased in average age. Furthermore, none of those weapon systems, including aircraft, has experienced marked or sustained growth in O&M costs over the past two decades.

5. Of course, individual pieces of equipment do age each year. Average ages, as discussed in this section, are derived from combining the ages of all of the types of a given weapon system (for example, the average age of tanks includes the ages of all of the different types of tanks that the Army possesses in a given year).

BOX 2.
THE HISTORICAL FUTURE YEARS DEFENSE PROGRAM

The Historical Future Years Defense Program (FYDP) database contains a historical record of costs, forces, and manpower—more than 10,000 individual items called program elements. The data are aggregated in various ways. One way is by defense mission category: major force missions (DMC1); defense-wide missions (DMC2); and defense-wide support missions (DMC3). DMC1 includes spending on tactical air forces, land forces, and naval forces and covers most equipment-related spending. DMC2 includes spending on command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). DMC3 covers items such as health care, supply operations, and personnel acquisition. Each defense mission category includes all types of defense spending, including spending on procurement; military personnel; research, development, testing, and evaluation; and operation and maintenance (O&M).

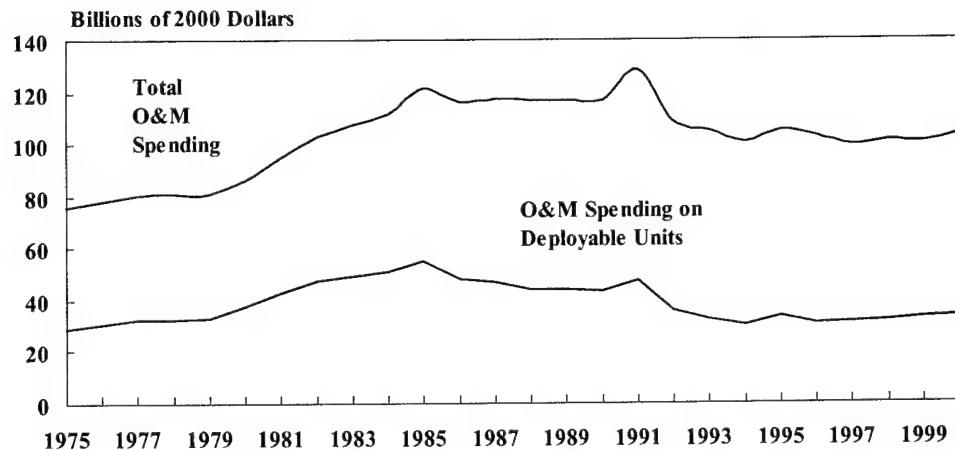
The FYDP data analyzed in this section have been adjusted to take into account changes in definitions of funding categories from 1975 to 2000. Both the Institute for Defense Analyses and the Office of the Assistant Secretary of Defense for Program Analysis and Evaluation made those adjustments to allow for better comparisons of spending on O&M over time. For example, from the late 1980s to the early 1990s, spare parts were purchased with procurement dollars, so one adjustment moved those purchases to O&M, where they occur in the current budget.

CBO's findings are in conflict with the services' statements that spending on O&M for equipment is growing rapidly. Those statements are sometimes based on selective data. The Air Force Chief of Staff recently testified that over the past five years, costs per flying hour have risen by almost 50 percent.⁶ That figure used 1996 as the base year—a year in which the Air Force says spare parts were underfunded because of errors in forecasting.⁷ If data for 1995 through 2000 are used instead, the measured growth is only 10 percent for the period. Similarly, the Army estimates that over the past three years, the costs of spare parts for five weapon systems—the Abrams Tank; the Bradley Fighting Vehicle; and the Black Hawk, Chinook, and Apache helicopters—have gone up 30 percent. But that figure reflects costs in only selected operating units. Total Army-wide spending on spare parts per operating hour for those five systems rose by 12 percent over the past six years—an average of 2 percent a year.

6. Statement of General Michael E. Ryan, Chief of Staff, U.S. Air Force, before the Senate Committee on Appropriations, June 6, 2001.

7. Statement of General Thomas Moorman, Jr., former Vice Chief of the Air Force, before the House Committee on National Security, October 7, 1998.

FIGURE 3. OPERATION AND MAINTENANCE SPENDING ON DEPLOYABLE UNITS COMPARED WITH TOTAL OPERATION AND MAINTENANCE SPENDING, 1975-2000



SOURCE: Congressional Budget Office based on data from the Department of Defense's Historical Future Years Defense Program database.

NOTES: With the exception of increased operation and maintenance (O&M) spending during the Persian Gulf War, the decline in both total O&M spending and O&M spending on deployable units coincides with an overall reduction in forces since the height of the Reagan defense buildup in 1985.

As described in Box 2, the O&M portion of defense mission category 1 (DMC1), major force missions, pays for most spending on deployable units and covers the costs to train and operate combat forces, including most equipment-related O&M spending. "O&M spending on deployable units" covers DMC1 spending minus funding for base operating support, the upkeep of intercontinental ballistic missiles, and management by headquarters. However, O&M spending on deployable units includes more than spending on equipment. For example, in 1999, spending on deployable units, at \$33 billion, was more than the \$20.3 billion discussed in the previous section, which reflected O&M spending on military equipment. Although spending on deployable units captures other nonequipment expenses, the measure still provides some trend information on equipment spending.

Age of and Spending on O&M for Ships. The data on the average age of and spending on O&M for ships do not support the view that aging ships account for increasing O&M costs. The average age of ships today is about what it was 20 years ago. And, according to data from 1984 to 1999, costs did not grow in those areas most closely tied to ship operations—spending on O&M for steaming hours per ship and major overhauls at depots.⁸

The average age of major battle force ships (carriers, destroyers, cruisers, amphibious ships, and submarines) was 14.5 years in 2000, compared with 13.6 years in 1980 (see Table 2). The average age grew in the 1980s as the Navy attempted to

8. Cost per steaming hour is defined as the hourly cost of operating a ship. It covers fuel costs; consumables, such as bearings and washers; and the repair of major subsystems, such as radars or engines (depot-level reparables).

create a 600-ship fleet and retained older equipment; by 1990, the average age was more than 16 years. But during the 1990s, reductions in the size of the fleet allowed the service to retire many of its oldest ships, so the average age of ships decreased to its current level.

With the exception of increased spending in 1992 following Operation Desert Storm to clear maintenance backlogs, O&M costs per steaming hour for the active fleet of ships changed little from 1984 to 1999 (see Figure 4). Aside from that effect of Desert Storm, spending per operating hour has remained level at just under \$1,200 per hour.

In contrast, spending on depot maintenance declined from \$15.3 million per ship in 1984 to \$9.0 million in 1999, a drop of 41 percent (see Figure 5). That decrease could have resulted from building ships that require less maintenance, shifting the maintenance workload from depots to other repair facilities, or delaying maintenance until absolutely necessary. In any event, those aggregate cost figures do not provide evidence of rising costs to operate and maintain ships.

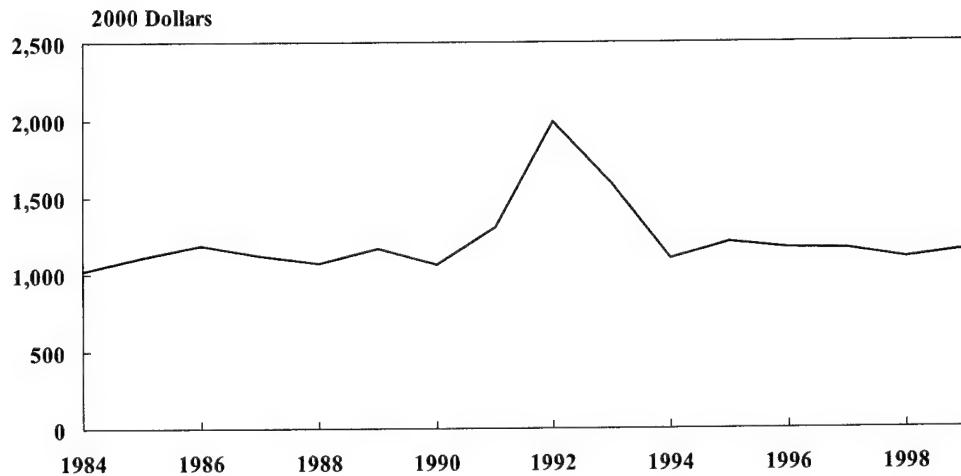
Age of and Spending on O&M for Aircraft. Unlike the average age of Navy ships, the average age of both Navy (including Marine Corps) and Air Force aircraft did increase over the past two decades. Between 1980 and 2000, the average age of active-service Navy aircraft rose from 11 years to more than 16 years (see Figure 6). Over the same period, the average age of active-service Air Force aircraft climbed from 13 years to more than 20 years (see Figure 7). For the Air Force, such aging is not a new trend. The average age of Air Force aircraft doubled in the 25 years from 1949 to 1974—from nearly 5 to 10 years—and again in the 25 years from 1975 to 1999—from 10 to 20 years. The average age of aircraft in the Air National Guard and Air Force Reserve has also risen since the 1970s, with most of the increase taking place in the 1990s.

TABLE 2. AVERAGE AGE OF MAJOR BATTLE FORCE SHIPS, 1980-2000 (In years)

	1980	1985	1990	1995	2000
Average Age	13.6	15.4	16.8	13.5	14.5

SOURCE: Congressional Budget Office based on data from the Department of Defense.

FIGURE 4. OPERATION AND MAINTENANCE SPENDING PER OPERATING HOUR FOR SHIPS, 1984-1999



SOURCE: Congressional Budget Office based on data from the Navy's Visibility and Management of Operating and Support Costs database.

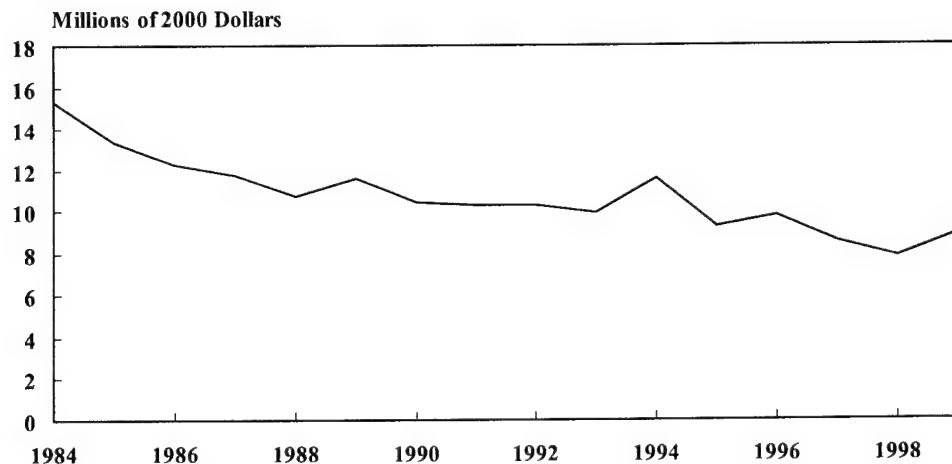
NOTE: Operation and maintenance spending includes expenses for consumables (for example, items such as washers, filters, and gaskets), depot-level reparables (for example, spare parts, radars, and engine components), and fuel.

Yet even if aging resulted in higher O&M costs than there otherwise would have been, a review of expenditures per flying hour and depot maintenance costs per aircraft provides no evidence that the costs of operating and maintaining aircraft are putting pressure on the services' total O&M budgets.⁹ The Navy's and Air Force's spending per flying hour and spending on depot maintenance per aircraft have not shown rapid growth (see Figures 8 through 11). To the extent that age has increased the costs of maintaining a particular type of aircraft, those increases may have been offset by other factors, including changes in management practices or simply reduced levels of readiness.

O&M Spending per Flying Hour. The Navy's spending declined from 1986 to 1989 but then rose throughout the 1990s (see Figure 8).¹⁰ Costs per flying hour increased

- 9. Cost per flying hour is defined as the hourly cost of operating an aircraft. It covers fuel costs; consumables, such as bearings and washers; and the repair of major subsystems, such as radars, avionics, or engines (depot-level reparables).
- 10. Based on data from the Navy's Visibility and Management of Operating and Support Costs database, which records flying-hour costs and the total number of hours flown annually. Flying-hour costs may be overstated because the Navy recorded the costs of "contractor logistics support" (CLS) in the category "consumables" in some years when they should have been recorded elsewhere.

FIGURE 5. MAINTENANCE SPENDING PER SHIP AT NAVY DEPOTS, 1984-1999



SOURCE: Congressional Budget Office based on data from the Navy's Visibility and Management of Operating and Support Costs database.

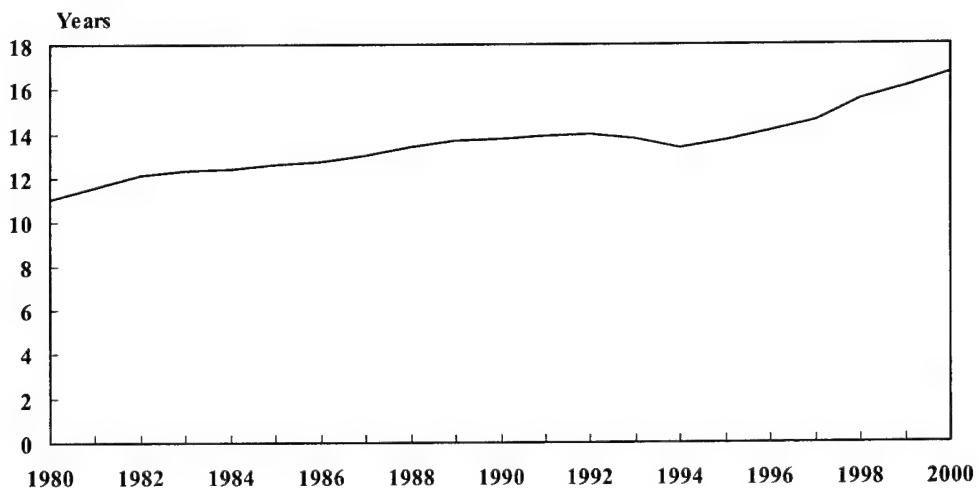
NOTE: Includes spending on the inspection, maintenance, and repair of military equipment—excluding depot-level reparables—at large public (Department of Defense) and private (contractor) depots.

from a low of \$1,500 in 1989 to \$2,200 in 1999. But in percentage terms, spending on flying hours in 1999 was nearly the same as in 1989—constituting 14 percent of the Navy's total spending on O&M in 1999, and 13 percent in 1989.

The Air Force's spending on O&M per flying hour fluctuated over the 25 years from 1975 to 1999 (see Figure 9).¹¹ It rose during the first half of the 1980s, possibly because of underspending in the 1970s or the Reagan defense buildup of the 1980s. From the peak of defense spending in 1986, spending per flying hour declined until 1991. After that it grew steadily; but even so, costs per hour in 1999 were no higher than they had been in 1986.

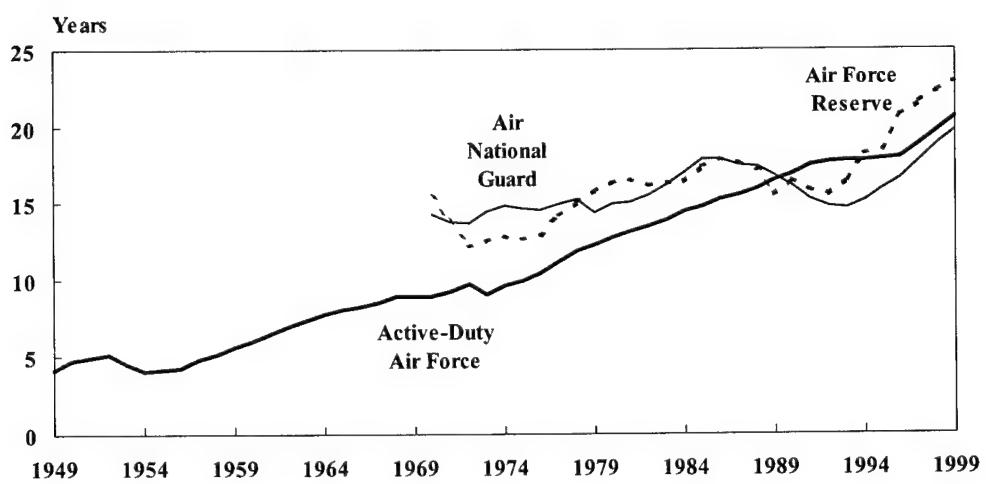
11. Because the Air Force Total Ownership Costs data go back only to 1996, CBO used Historical FYDP data to determine the cost of operating Air Force aircraft. The total annual flying hours came from the *Air Force Statistical Digest*. CBO created a ratio by dividing the Air Force's spending on O&M in defense mission category 1 (DMC1) by the total number of hours flown by aircraft in a year. However, the O&M portion of DMC1 includes many costs not directly associated with operating equipment, such as spending on headquarters management and base operating support. As a result, CBO's figures for spending per operating hour do not reflect actual costs per hour (for fuel, consumables, and depot-level reparables) but include other O&M expenses as well. Nonetheless, if higher O&M costs were being driven by aging equipment, some relationship between costs and time might be expected in these data.

FIGURE 6. AVERAGE AGE OF NAVY AIRCRAFT, 1980-2000



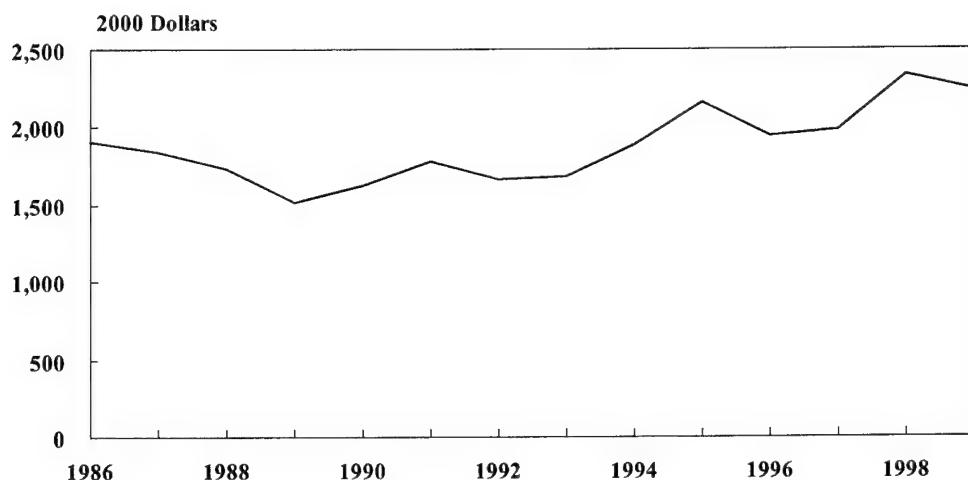
SOURCE: Congressional Budget Office based on data from the Department of Defense.

FIGURE 7. AVERAGE AGE OF AIR FORCE AIRCRAFT, 1949-1999



SOURCE: Congressional Budget Office based on data from the Department of Defense.

FIGURE 8. OPERATION AND MAINTENANCE SPENDING PER OPERATING HOUR FOR NAVY AIRCRAFT, 1986-1999



SOURCE: Congressional Budget Office based on data from the Navy's Visibility and Management of Operating and Support Costs database.

NOTE: Operation and maintenance spending includes expenses for consumables (for example, items such as washers, filters, and gaskets), depot-level reparables (for example, spare parts, avionics, and engine components), and fuel.

Spending on Depot Maintenance per Aircraft. The Navy's spending on depot maintenance per aircraft over the 15 years from 1986 to 2000 varied between \$130,000 and \$275,000 (see Figure 10).¹² The large spikes from 1990 to 1993 suggest that spending on depot maintenance was first increased to prepare for the Gulf War, then deferred until the end of the conflict in 1991.

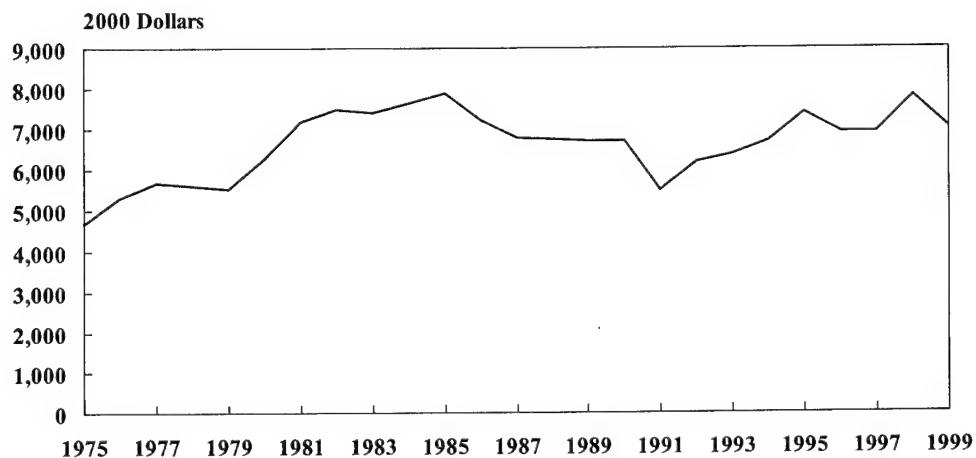
The Air Force's spending on depot maintenance per aircraft fluctuated over the 25 years from 1975 to 1999 (see Figure 11).¹³ Spending grew in the early 1980s, perhaps reflecting the relatively generous budgets during the Reagan defense buildup. Subsequently, depot spending per aircraft declined as the defense budget in general declined. After the Air Force switched its method of accounting in 1993, spending on depot maintenance per aircraft flattened out.

12. Based on data from the Navy's Visibility and Management of Operating and Support Costs database, which records depot maintenance costs and the total inventory of aircraft annually.

13. Based on data from the Air Force's Depot Maintenance Weapon System Cost Data Reports, HO-36. Information on the aircraft inventory came from the *Air Force Statistical Digest*.

The lack of strong, continuous growth in O&M costs for aircraft over the past two decades does not mean, of course, that age and costs are unrelated. Many factors other than the condition of equipment affect the cost of operating and maintaining aircraft. Trends in costs could reflect less the condition of aircraft than changes in maintenance policy and budgets. Fuel costs, maintenance efficiency, accounting policies, the closure of depots resulting from the Base Realignment and Closure Commission, shifting workloads between organizational levels of maintenance facilities, and other factors may offset increased equipment costs, masking the true amount of cost growth. Any of those factors could explain why spending per aircraft has not shown sustained growth over the past decade. But what is clear is that there is no evidence that the costs of operating and maintaining aircraft have led to rising aggregate O&M costs.

FIGURE 9. OPERATION AND MAINTENANCE SPENDING PER OPERATING HOUR FOR AIR FORCE AIRCRAFT, 1975-1999



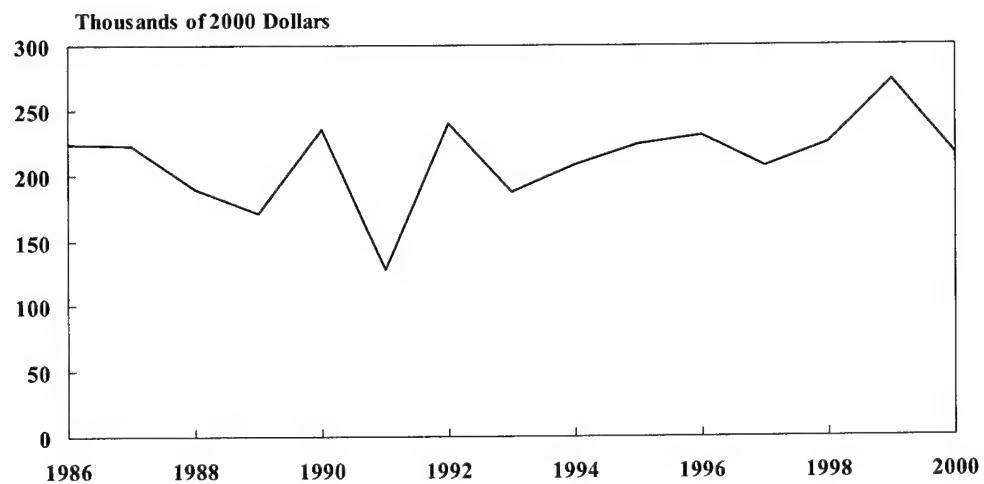
SOURCE: Congressional Budget Office based on data from the Department of Defense's Historical Future Years Defense Program database.

NOTE: The Air Force's costs per operating hour are not comparable to the Navy's costs in Figure 8. The spending per hour presented here for the Air Force reflects operation and maintenance (O&M) for deployable units, which includes costs for consumables (for example, items such as washers, filters, and gaskets), depot-level reparables (for example, spare parts, avionics, and engine components), and fuel, along with other expenses for such things as base operating support and management by headquarters. Nonetheless, if higher O&M costs were being driven by aging equipment, some relationship might be expected between costs and time in these data.

Age of and Spending on O&M for Army Equipment. The average age of and spending on O&M for equipment in the Army are particularly difficult to analyze because those pieces of equipment—armored vehicles, tanks, and helicopters—number in the hundreds of thousands, and the data on historical operating costs are limited. Nonetheless, the available data on tactical wheeled vehicles and tanks show that their average age in 1999 was lower than a decade before and that the costs to operate two of the highest-cost ground systems fell from 1993 to 1999. And although the average age of the Army's helicopter fleet has increased by more than 70 percent since 1980, O&M spending for two of the three most costly types of helicopters did not increase greatly in the 1990s.

Army Ground Systems. The Army modernized its ground systems in the 1980s, bringing in new equipment, which decreased the average age of some types of systems, including tanks and tactical wheeled vehicles. According to data from the Office of the Secretary of Defense, the average age of all Army tanks was slightly lower in 1999 than in 1980, 11 years versus 12 years. Furthermore, according to the

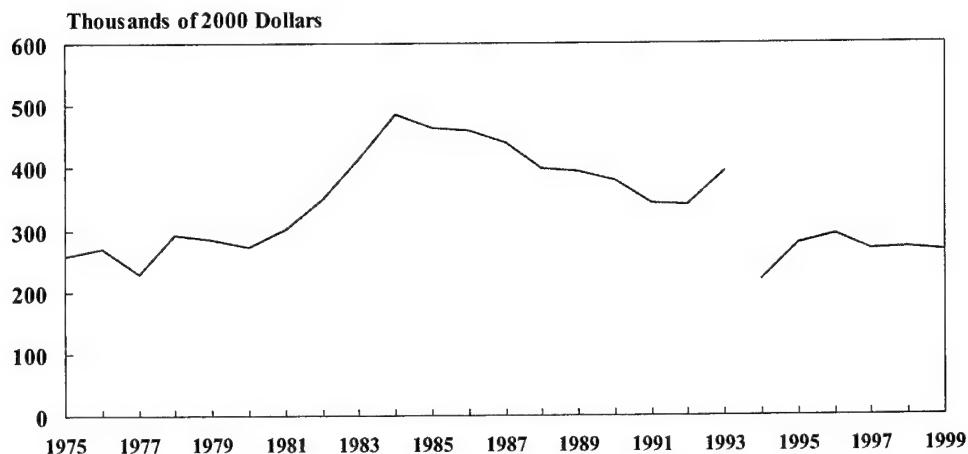
FIGURE 10. MAINTENANCE SPENDING PER AIRCRAFT AT NAVY DEPOTS, 1986-2000



SOURCE: Congressional Budget Office based on data from the Navy's Visibility and Management of Operating and Support Costs database.

NOTE: Includes spending on the inspection, maintenance, and repair of military equipment—excluding depot-level reparables—at large public (Department of Defense) and private (contractor) depots.

FIGURE 11. MAINTENANCE SPENDING PER AIRCRAFT AT AIR FORCE DEPOTS,
1975-1999



SOURCE: Congressional Budget Office based on data from the Air Force's Depot Maintenance Weapon System Cost Data Reports.

NOTES: Includes spending on the inspection, maintenance, and repair of military equipment—excluding depot-level reparables—at large public (Department of Defense) and private (contractor) depots.

The break in data between 1993 and 1994 is due to changes in accounting methods, including a shift to a working capital fund for unit purchases of spare parts and depot repairs.

Army's testimony before the Congress, the average age of its tactical wheeled vehicles in 1999, 13 years, represents a decrease from that of the 1980s.¹⁴

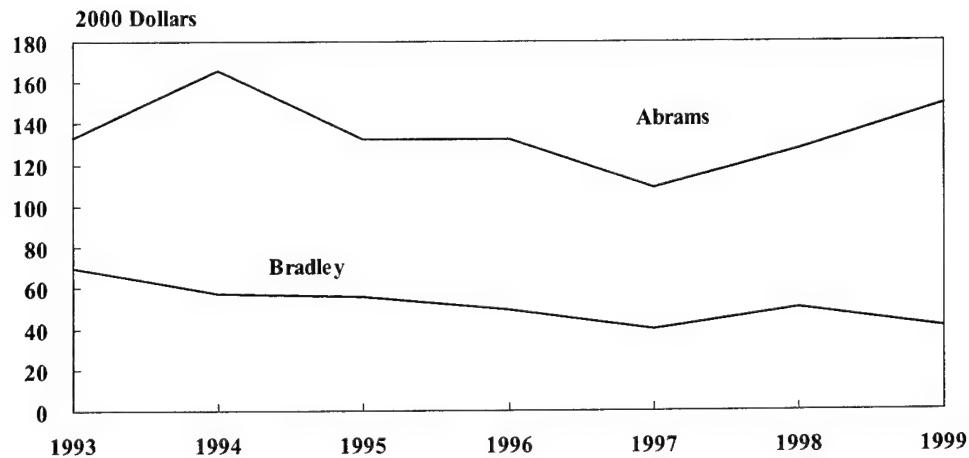
CBO's review of the Army's O&M data from 1993 to 1999 shows that the costs of consumables and repair parts per mile for the two most expensive ground systems to operate—the Abrams Tank and the Bradley Fighting Vehicle—declined by 7 percent over that period, going from an average of \$102 per mile to \$95 per mile (see Figure 12).¹⁵

Army Helicopters. For the Army's helicopter fleet, the average age grew from 10.2 years in 1980 to 17.6 years in 2000 (see Table 3). That 70 percent increase occurred while the inventory shrank by roughly 30 percent, going from just over 7,100 helicopters in 1980 to just under 5,000 by September 2000.

14. Statement of Lieutenant General John G. Coburn, Deputy Chief of Staff for Logistics, Department of the Army, before the House Committee on Armed Services, February 24, 1999.

15. Based on data from the Army's Operating and Support Management Information System database, covering 1993 to 1999. Costs per mile include those for consumables and depot-level reparables but not for fuel.

FIGURE 12. SPENDING ON CONSUMABLES AND REPARABLES PER MILE
FOR THE ARMY'S ABRAMS TANK AND THE BRADLEY
FIGHTING VEHICLE, 1993-1999



SOURCE: Congressional Budget Office based on data from the Army's Operating and Support Management Information System database.

NOTE: Spending includes expenses for consumables (for example, items such as washers, filters, and gaskets) and depot-level reparables (for example, spare parts and engine components).

CBO's review of the Army's O&M data from 1993 to 1999 shows that the costs of consumables and repair parts per flying hour for the three most expensive helicopter systems to operate—the Black Hawk, Chinook, and Apache helicopters—increased by 13 percent over that period.¹⁶ However, closer examination reveals that the costs per flying hour for the Chinook helicopters, which increased by more than 40 percent between 1993 and 1999, accounted for most of that growth (see Figure 13). The Black Hawk's and Apache's costs per flying hour remained relatively steady, with the former decreasing by 4 percent and the latter increasing by 3 percent.

Again, while the ages and operating costs of the hundreds of thousands of pieces of Army equipment remain unavailable for analysis, the limited data that are available on five of the most expensive systems do not support assertions that costs for all aging systems are rising rapidly.

16. Based on data from the Army's Operating and Support Management Information System database, covering 1993 to 1999. Costs per hour include those for consumables and depot-level reparables but not for fuel.

TABLE 3. AVERAGE AGE OF ARMY HELICOPTERS, 1980-2000 (In years)

	1980	1985	1990	1995	2000
Average Age	10.2	13.9	15.7	16.8	17.6

SOURCE: Congressional Budget Office based on data from the Army Materiel Command.

NOTE: Helicopters include the UH-1, UH-60, OH-58, OH-58D, CH-47, CH-47D, AH-1, and AH-64.

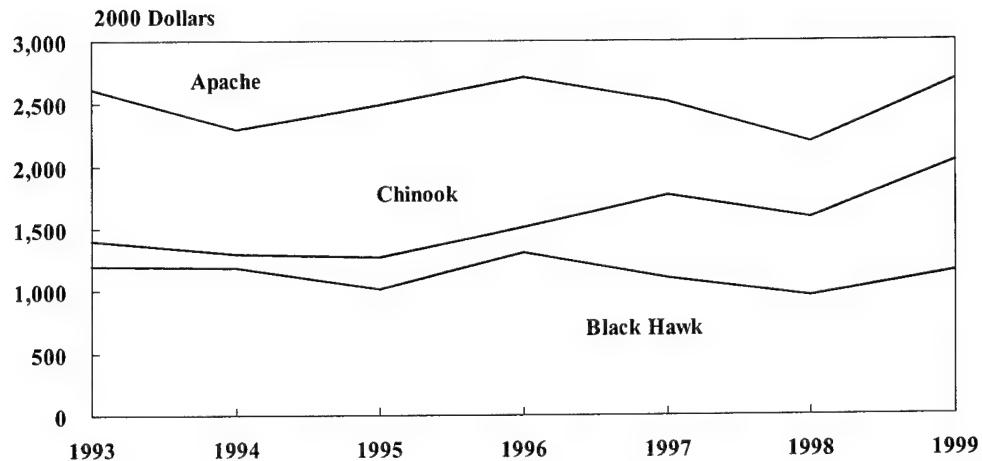
The Need for Detailed Analyses by Weapon System

CBO's analysis provides no evidence that equipment costs are driving up the overall O&M budget. Nonetheless, as almost all types of military equipment increase in average age over the next decade, the costs of operating and maintaining that equipment may increase to the point at which they affect aggregate spending on O&M.¹⁷ Moreover, CBO's analysis does not rule out a relationship between the age and the costs of operating individual systems. It is possible that the cost of operating equipment rises with age but that the increase is not paid for with O&M funds, as would be the case for higher labor costs for increased maintenance (paid under personnel accounts) or certain modifications to equipment (paid under procurement accounts). Or perhaps increasing costs due to aging are being offset by management initiatives and improved maintenance techniques.

The next section of this paper looks at individual weapon systems to determine if there is a relationship between age and costs that could contribute to the growth in O&M costs in the long run. CBO examines how age affects individual weapon systems, the impact aging has on the costs of those systems, and the implications for the future.

17. Despite planned purchases of the F/A-18E/F, Joint Strike Fighter, and F-22, the average ages of the fleets of Navy and Air Force aircraft are expected to continue increasing. The average ages of ships and armored vehicles are also expected to rise. Only Army helicopters, because of the expected retirement of aged UH-1s and OH-58s in the near future, are expected to decrease in average age in the coming decade.

FIGURE 13. SPENDING ON CONSUMABLES AND REPARABLES PER HOUR FOR THE ARMY'S APACHE, CHINOOK, AND BLACK HAWK HELICOPTERS, 1993-1999



SOURCE: Congressional Budget Office based on data from the Army's Operating and Support Management Information System database.

NOTE: Spending includes expenses for consumables (for example, items such as washers, filters, and gaskets) and depot-level reparables (for example, spare parts, avionics, and engine components).

THE EFFECTS OF AGING ON THE COSTS OF OPERATING AND MAINTAINING AIRCRAFT

CBO finds no evidence that there has been cost growth in total O&M spending because of aging equipment. However, analysts predict that the average ages of ships, aircraft, and armored vehicles will rise in the future, in some cases to unprecedented levels. That trend could eventually lead to much higher O&M costs for equipment, which could in turn lead to higher total O&M spending.

As systems pass their initial years of operation and begin to age, engineers expect operating costs to rise because of fatigue, corrosion, and the obsolescence of parts. Although there are few empirical studies on the effects of age on equipment, many of the studies that do exist focus on the effects of age on aircraft. Those studies typically have found that the costs of operating and maintaining aircraft increase by

1 percent to 3 percent with every additional year of age, after adjusting for inflation.¹⁸ (Equipment costs in those studies have included the costs of the military personnel who operate and maintain the aircraft, as well as the costs of fuel, spare parts, and civilian maintenance personnel.) However, the relationship between age and costs is complex. Costs are likely to be affected by the age and types of components of the aircraft, the number of hours and the way in which the aircraft is flown, and the resources devoted to maintaining the aircraft over time. Moreover, the relationship between age and costs may change as the age of aircraft increases beyond the ranges observed in those studies.

Additional studies that would focus on individual pieces of equipment might help to reduce uncertainty about the effects of age. Such studies could identify the effects by tracking failure rates, maintenance actions, and the associated costs for individual aircraft of a particular type. And the effectiveness of recapitalization—time-consuming and costly maintenance procedures intended to reverse the effects of aging and bring equipment to “like-new” condition—could be tested by putting into the same unit both recapitalized equipment and equipment that has not been refurbished and tracking their costs.

Expected Effects and Examples of Aging Equipment

Fatigue, corrosion, and obsolete parts explain why many analysts expect failure rates, maintenance actions, and associated costs to rise as equipment becomes older.

Fatigue, Corrosion, and Obsolete Parts. Fatigue refers to the weakening or failure of material, such as metal, that results from prolonged stress. Bending a paper clip two or three times causes it to snap—the result of fatigue. All aircraft, ships, and vehicles have moving parts and parts under stress that are susceptible to cracking or breaking over time. But effects of fatigue are not easy to predict. Although engineers attempt to model probabilities of fatigue when estimating service lives for pieces of equipment, those pieces are never used in exactly the same way as in a laboratory environment. Moreover, as systems reach the end of their estimated service lives, the risk of cracks or breaks because of fatigue can increase dramatically.

Corrosion is the gradual destruction of a metal or alloy by oxidation or chemical action. The tendency of most metals to oxidize (rust) when left untreated

18. Many engineers hold the view that a graph of the operating costs of equipment takes on a bathtub shape, whereby costs initially start high, then decline after initial glitches and design flaws are corrected. Next comes a long period of low or level costs. In later years, under that view, operating costs rise rapidly. Although some systems have exhibited a cost curve similar to the first part of the tub in the initial years of operation, and most studies on equipment report relatively low levels of O&M cost growth, no study has shown the rapidly rising costs that would correspond to the far end of the tub.

and exposed to air and moisture is an example. Each service recognizes the problems presented by corrosion. It is even more difficult to predict than fatigue, in part because it depends so much on the environment in which the equipment is operated. Nonetheless, corrosion is an important factor for aging equipment. The Air Force considers corrosion the biggest problem it faces with aging equipment; Army reports call it “the silent enemy”; and Navy studies detail the difficulties of maintaining aging equipment in a corrosive saltwater environment.

Obsolete parts are items that are outmoded in design or that rely on production lines or technologies that are no longer used. Many aging systems are expensive to maintain because the original manufacturer no longer makes the required parts. In some cases, the original engineering diagrams are missing, or the government never bought the rights to the drawings, forcing a new manufacturer to redesign the items. In addition to increasing the costs of replacement parts, obsolescence can result in long delays in filling orders, with some orders taking from 18 months to two years to be filled.¹⁹

Obsolescence is a particularly serious problem for advanced instruments and electronics. For example, although designs for computer chips in the civilian market become obsolete every 18 months, military equipment can use electronics and computer designs dating as far back as the 1960s. As late as the 1980s, the military accounted for a significant share of the world market for chips and could keep manufacturers producing the designs it needed. Now, however, the commercial world dictates the designs, making it more difficult for DoD to find suppliers. According to a report by Oklahoma State University, obsolete parts for aircraft are an increasing problem for the services.²⁰

Anecdotal Evidence About the Effects of Fatigue, Corrosion, and Obsolete Parts. Concern about the effects of fatigue, corrosion, and obsolete parts has been spurred in part by specific instances in which the age of aircraft has been linked to maintenance problems or reduced safety. Air Force experts cite the example of the KC-135, a 40-year-old aircraft that is becoming both less reliable and increasingly costly to maintain (see Box 3). In the case of civilian aircraft, there are at least two instances of catastrophic failure linked to aging. In 1988, part of the fuselage of an aircraft operated by Aloha Airlines—weakened by corrosion and fatigue—ripped off

19. Statement of William J. Lynn, III, Under Secretary of Defense (Comptroller and Chief Financial Officer), before the House Committee on Armed Services, October 7, 1999.

20. See Computer Assisted Technology Transfer (CATT) Program, Oklahoma State University, *Parts on Demand Project (CATT Phase II)* (prepared for Major Joseph Steil, CATT Program Manager, December 31, 1996), available at <http://catt.bus.okstate.edu/catt2/PHASE2/exec3.htm#3.3>. The CATT Program is a cooperative effort among government, academia, and industry initiated in 1994 to address procurement problems facing the Department of Defense.

BOX 3.

THE KC-135 STRATOTANKER: INCREASING AGE
AND INCREASING OPERATION AND MAINTENANCE COSTS

The KC-135 stratotankers, many of which are 40 years old, are some of the oldest aircraft the services operate. And they are becoming more expensive to operate; the cost per flying hour increased from \$8,539 in 1996 to \$11,128 in 2000 (after adjustments for inflation).¹ The military has little or no experience operating and maintaining aircraft of that age, and no commercial airline fleets of a comparable age exist. Consequently, the Air Force recently began collecting data to enable it to predict how long or effectively those aircraft can continue to operate.

As the KC-135 tankers age, they require more maintenance, reducing the number of aircraft available for operations. For example, between fiscal years 1991 and 1995, the labor hours planned to complete depot overhauls of the KC-135s increased by about 36 percent, and the average time aircraft spent in the depot increased from 158 days to 245 days. According to Air Force officials, the growth in planned work included time to apply compounds that prevent corrosion and to rewire significant portions of each aircraft. In addition, according to a report by the General Accounting Office, "Shortages of spare parts, that were no longer in production or stocked, and unplanned work, required to correct structural corrosion and fatigue, contributed to maintenance delays and reduced aircraft availability."²

1. Based on data from the Air Force Total Ownership Costs database.

2. General Accounting Office, *U.S. Combat Air Power: Aging Refueling Aircraft Are Costly to Maintain and Operate*, GAO/NSIAD-96-160 (August 1996).

in flight. And aging wiring is believed to have contributed to the crash of TWA Flight 800 off Long Island in 1996.

Those examples are consistent with the intuitive notion that the problems posed by fatigue, corrosion, and obsolete parts increase with the age of systems. Other examples, however, suggest that the relationship between age and such problems is not so clear. For example, some types of older aircraft—including the Navy's CH-46 and the Army's UH-60—do not appear to be experiencing increasing O&M costs (see Box 4). The CH-46 underwent major modifications in the late 1980s, which kept O&M costs down in the 1990s. The UH-60 fixed longstanding technical problems in the mid-1990s, reducing O&M costs.²¹

21. It is important to note that some major modifications, such as the CH-46's, are funded through procurement accounts. Looking only at O&M costs may underestimate the true costs of aging for such systems, although including all costs from procurement accounts for major modifications, some of which are intended to upgrade capability, would overestimate the effects of age.

BOX 4.

THE CH-46 SEA KNIGHT AND THE UH-60 BLACK HAWK:
INCREASING AGE AND CONTROLLED
OPERATION AND MAINTENANCE COSTS

The CH-46 Sea Knight. The CH-46 helicopter, the workhorse of Navy and Marine tactical transportation squadrons, first introduced during the Vietnam War, is now more than 30 years old.

During the 1980s and 1990s, Boeing developed modification kits and upgrades to modernize the Sea Knights. The kits, which were aimed at extending the fleet's performance, safety, economy, and longevity well into the next century, have succeeded so far. According to the Navy's data, a modernized CH-46 fleet operated economically through the 1990s—at a cost per flying hour that in 1997 nearly equaled the cost 11 years earlier (after adjustments for inflation).

The Sikorsky UH-60 Black Hawk. First deployed in 1978, the Black Hawk is the Army's front-line utility helicopter. It performs various missions, including air assault, air cavalry, and medical evacuations.

While the average age of the Black Hawk fleet more than doubled from 1990 to 2000, from 5.9 to 12.7 years, O&M spending per flying hour remained stable. From 1993 to 1999, the cost of consumables and reparables per flying hour fluctuated between \$960 and \$1,300 (after adjustments for inflation).¹ And, from 1996 to 1999, spending decreased by 12 percent. The Army expects a program begun in 1999 to keep the fleet operationally effective through 2025 or 2030—nearly doubling the original service life expectancy of 25 years.

1. Based on data from the Army's Operating and Support Management Information System database.

An often cited analogy in discussions of aging aircraft is the family car, which can cost more to keep on the road as it gets older. However, in the case of aircraft, a number of other factors may offset the expected adverse effects of age. The extensive periodic maintenance and safety checks of military equipment, along with piecemeal replacement and modifications of equipment, may invalidate the car analogy. In addition, the effects of age on any individual aircraft will depend on the environment in which that aircraft is used and how intensively it is used. Anecdotal evidence and analogies are not an adequate basis for policy; instead, quantitative studies that allow analysts to take all of the relevant factors into account are needed to determine both what effects age has on costs and what could be done to offset those effects.

The Relationship Between Costs and Aircraft Age

Although the services have presented numerous briefings on the relationship between costs and age, CBO's literature review found just seven studies that have gone beyond the anecdotal evidence and attempted to identify a quantitative relationship between the age of aircraft and breakdown rates, the time spent on maintenance, and the cost of operation and maintenance (see Appendix B for a list of those studies). Most of those analyses conclude that age does cause higher operation and maintenance costs—and higher operation and support (O&S) costs, which are O&M costs plus the cost of military personnel—often citing cost increases ranging from 1 percent to 3 percent for every additional year of age. Analyses of the time between breakdowns and the time spent fixing equipment also indicate that age has an effect. According to those studies, an additional year of age may decrease the time between breakdowns from 1 percent to 7 percent and increase downtime from 1 percent to 9 percent. However, the quality of the studies and the credibility of their results vary.

Studies Based on Data for Individual Aircraft. The most credible studies are those that link costs or maintenance actions to individual airframes or engines. That approach allows, over a brief period of time, multiple observations of pieces of equipment that are of the same design but differ in age. As a result, those studies are best able to distinguish accurately the effects of age from the effects of other factors, such as changes in accounting or maintenance policies over time. There are only a small number of such studies—including one completed by the cost department in the Naval Air Systems Command (NAVAIR, formerly part of the Naval Aviation Maintenance Office; see Table 4, Study 2) and three studies by the Center for Naval Analyses (CNA; see Table 4, Studies 1, 3a, and 3b)—but they all find evidence that aging increases O&M costs.

In an August 1993 study, NAVAIR analyzed 10 to 15 years of data for five types of aircraft (the F-14, F/A-18, E-2, CH-53, and C-2). Collecting and analyzing data by aircraft service year (the year a specific aircraft became operational), the study demonstrated the effect of age on costs. According to that study, as aircraft aged, failure rates and direct maintenance man-hours increased (direct maintenance man-hours include maintenance by military personnel that occurs in or near the field, as opposed to maintenance accomplished predominantly by civilians at depots). The annual increase in the rate of failures per operating hour was approximately 1 percent to 7 percent, and the increase in depot maintenance man-hours per flight hour was approximately 2 percent to 8 percent.

In a 1991 study, the Center for Naval Analyses linked ages to costs by estimating the relationship between depot-level maintenance costs and the ages of five types of aircraft (the F-14, E-2, A-6, P-3, and H-46). While differing by aircraft type, depot maintenance generally includes the inspection, maintenance, and replacement of multiple components. Using data on individual aircraft from 1984 to 1989, which

allowed multiple observations of the various types of aircraft in each year, CNA estimated separate relationships between age and costs for each type of aircraft while distinguishing between the effects associated with a specific calendar year and those associated with the age of individual aircraft. That study found that depot maintenance man-hours rose 0.8 percent to 1.4 percent per year of age, while materiel costs increased 0.9 percent to 3.4 percent per year. But because that study focused only on maintenance that was conducted at depots, it shed no light on maintenance activities performed at units (organizational-level maintenance) or at intermediate repair facilities (intermediate-level maintenance), the costs of which may have behaved differently.

CNA recently concluded two other promising, albeit preliminary, studies. In the first, CNA examined all F/A-18s from 1990 to 1999, collecting and analyzing detailed maintenance data by individual aircraft. Each observation, taken by month, included the total number of flights, amount of time flown, maintenance time at the organizational-level facilities, and age of the aircraft. The resulting database of more

TABLE 4. STUDIES BASED ON DATA FOR INDIVIDUAL AIRCRAFT

Author/Date	Equipment Examined	Observations	Estimated Effect of an Additional Year of Age
(1) Center for Naval Analyses/ March 1991	Five Navy aircraft (the F-14, E-2, A-6, P-3, and H-46) from 1984 to 1989.	Multiple observations per aircraft type per year based on the number of aircraft entering depots.	Maintenance man-hours increased by 0.8 percent to 1.4 percent. Materiel costs increased by 0.9 percent to 3.4 percent.
(2) Naval Air Systems Command/ August 1993	Five Navy aircraft (the F-14, F/A-18, E-2, CH-53, and C-2) from 1977 to 1992.	15 observations for the F-14, E-2, C-2; 10 observations for the F/A-18, CH-53.	Depot maintenance man-hours per flight hour increased by 2 percent to 8 percent. Rate of failures increased by 1 percent to 7 percent.
(3) Center for Naval Analyses/ March 2000	(a) All F/A-18 aircraft by month from 1990 to 1999. (b) All F/A-18C aircraft by individual sortie for June 1996.	(a) 27,000 observations. (b) 3,595 observations.	(a) Maintenance man-hours increased by 6.5 percent to 8.9 percent. (b) Probability of unscheduled maintenance increased by 0.8 percent.

SOURCE: Congressional Budget Office.

than 27,000 observations showed that a one-year increase in aircraft age was associated with an annual increase in maintenance man-hours ranging from 6.5 percent to 8.9 percent.

CNA's second preliminary study modeled the probability of breakdowns, or unscheduled maintenance, for the entire fleet of F/A-18Cs during a randomly selected month (June 1996). The analysis, which contained 3,595 observations of F/A-18C flights during the month, showed that a one-year increase in the age of an aircraft increased the probability of unscheduled maintenance by 0.8 percent.

Studies Based on Average Ages and Aircraft Types over Time. Less credible, but much easier to perform, are studies that use readily accessible aggregated data on the average age of a particular type of aircraft in a year and its maintenance costs. Such studies typically suffer from some serious weaknesses. Those that estimate the relationship between average age and cost separately for different types of aircraft are based on very few observations. Studies that fall into this category include a NAVAIR study from 1993 (see Table 5, Study 4), the RAND Corporation's study in 1998 (see Table 5, Study 5), and a regression analysis by the Air Force Cost Analysis Agency in 1999 (see Table 5, Study 6). Those studies typically have no more than 11 observations because changes in accounting practices and data collection limit the number of years covered. In addition, such data do not allow analysts to distinguish between the effect of age and the effect of any other variable (for example, changes in budgets or accounting practices).

Studies Based on Pooled Average Ages and Aircraft Types over Time. Other studies use average ages and costs but pool, or combine, both different years and data for different types of aircraft. That approach increases the number of observations and allows the effects of the equipment's age to be distinguished from the effects of other variables. Two such studies are a RAND paper in 1990 (see Table 6, Study 7) and CBO's own analysis (see Table 6, Study 8; see also Box 5 and Appendix A). The RAND study, using the Air Force's Visibility and Management of Operating and Support Costs data for 1981 to 1986, modeled operating and support costs for up to 74 different types and versions of aircraft. The analysis showed that as the average age of a type of aircraft increased by one year, O&S costs rose 1.7 percent per year.

However, underlying the use of pooled data is the questionable assumption that each type of aircraft is associated with the same age-related costs. CBO found increases in O&S and O&M costs due to aging using RAND's model, but those results disappeared when CBO accounted for the effects of different types of aircraft. Studies with pooled data may appear to be comprehensive but can be less reliable than those that concentrate on individual systems. In addition, if aircraft with a higher average age were designed earlier than aircraft with a lower average age, as one may expect, DoD's efforts to design systems to be less costly to maintain might cause studies using pooled data to overstate the effects of age on costs.

Addressing the Effects of Aging

In the foreseeable future, the average ages of almost all types of weapon systems will increase. Four basic approaches—which are not mutually exclusive—are available to address the risk that aging systems pose for safety, readiness, and costs. But making more informed decisions about those approaches requires better information than currently exists.

One approach is simply to allow equipment to age and to pay the associated increases in O&M costs. The implications of that approach for costs are uncertain but could possibly be large. The 1 percent to 3 percent increase in O&M costs for every year of age, after adjustments for inflation, typically found in studies of aircraft, combined with projections of equipment's age, translates into a wide range of potential future costs for the Air Force and the Navy. For the Air Force, the annual

TABLE 5. STUDIES BASED ON AVERAGE AGES AND AIRCRAFT TYPES OVER TIME

Author/Date	Equipment Examined	Observations	Estimated Effect of an Additional Year of Age
(4) Naval Air Systems Command/ July 1993	10 Navy aircraft (the P-3, S-3, CH-53, H-60, H-3, H-46, E-2, A-6, F-14, and F/A-18) from 1982 to 1992.	A maximum of 10 observations per aircraft.	Maintenance man-hours increased by 2 percent to 6 percent. Aircraft overhaul costs ranged from -2 percent to 10 percent. DLR and engine overhaul costs increased by 5 percent to 6 percent.
(5) The RAND Corporation/ October 1998	The KC-135 and commercial 727, 737, DC-9, and DC-10 aircraft.	Not available.	Programmed depot costs increased by 7 percent.
(6) Air Force Cost Analysis Agency/ March 1999	Air Force aircraft grouped by type (bomber, cargo/tanker, and fighter) using data from 1986 to 1996.	11 observations per type of aircraft.	Aircraft overhaul costs increased by 2.7 percent to 6.7 percent.

SOURCE: Congressional Budget Office.

NOTE: DLR = depot-level repairable.

increase could be \$80 million to \$230 million and between \$800 million and \$2.7 billion over 10 years. For the Navy, annual costs could increase \$40 million to \$130 million, or between \$450 million and \$1.5 billion over 10 years. Additionally, as the age of some systems gets beyond the levels documented in existing studies, costs could increase faster than the rates found in those studies.

A second approach is to tear down and rebuild existing equipment in an effort to return it to its condition when new. DoD rebuilds equipment through so-called recapitalization programs, or service life extension programs (SLEPs), which are less costly than new equipment would be. However, the costs of SLEPs, which often involve upgrading subsystems and parts, are substantial. In addition, the extent to which those programs are able to reduce O&M costs and increase the service lives

TABLE 6. STUDIES BASED ON POOLED AVERAGE AGES AND AIRCRAFT TYPES OVER TIME

Author/Date	Equipment Examined	Observations	Estimated Effect of an Additional Year of Age
(7) The RAND Corporation/ May 1990	Up to 74 types and versions of Air Force aircraft from 1981 to 1986.	400 observations.	Operation and support costs (O&M costs plus the costs of military personnel) increased by 1.7 percent, and O&M costs increased by 1.3 percent.
(8) Congressional Budget Office/ February 2001	(a) 17 Air Force fighter, attack, bomber, cargo, and helicopter aircraft from 1996 to 1999. (b) 13 Navy fighter, attack, cargo, and helicopter aircraft from 1986 to 1999. (c) 20 Navy and Air Force fighter, attack, and bomber aircraft from 1976 to 1999.	(a) 68 observations. (b) 164 observations. (c) 327 observations.	(a) O&S and O&M costs increased by 1 percent. (b) O&S costs increased by 2.4 percent, and O&M costs increased by 2.6 percent. (c) O&M costs increased by 2.5 percent.

SOURCE: Congressional Budget Office.

NOTE: O&M = operation and maintenance; O&S = operation and support.

BOX 5.
**RESULTS OF THE CONGRESSIONAL BUDGET OFFICE'S
REGRESSION ANALYSIS**

Duplicating the RAND Corporation's model, with data from the Air Force for 1996 to 1999, the Congressional Budget Office (CBO) also found growth in operation and support (O&S) costs—spending on operation and maintenance (O&M) plus spending on military personnel—and in O&M costs as aircraft increased in age.¹ For 17 types of aircraft in the active fleet (68 observations), O&S costs increased by 1 percent for each additional year of average age, and annual O&M costs increased 1 percent. Air National Guard and Air Force Reserve aircraft also showed cost growth, with each additional year of age increasing O&S costs 4 percent and 3 percent, respectively. Because of the range of uncertainty of those estimates, however, the difference for the active and reserve fleets may not reflect any difference in the actual effects of age.

CBO also used the Navy's data from 1986 to 1999 for 13 different Navy fighter, attack, cargo, and helicopter aircraft (164 observations).² With the type of aircraft, year, inventory, and pace of operations held constant, one additional year of age was associated with an increase in O&S costs of 2.4 percent per year and an increase in O&M costs of 2.6 percent per year. Splitting the data by year or by type of aircraft did not change the results significantly.

Finally, CBO used the Office of the Secretary of Defense's Historical Future Years Defense Program (FYDP) database (described in Box 2) to model long-term spending on O&M from 1976 to 1999. CBO analyzed trends in spending on O&M using program elements—the basic building blocks of the FYDP—for 20 types of active Navy and Air Force fighter, attack, and bomber squadrons (327 observations). An additional year of age was associated with an increase in O&M spending of 2.5 percent for those squadrons.

1. Based on data from the Air Force Total Ownership Costs database.

2. Based on data from the Navy's Visibility and Management of Operating and Support Costs database.

of pieces of equipment remains uncertain. Among the systems currently undergoing SLEPs are the Army's Abrams tank and the Navy's EA-6B aircraft.

A third approach is to buy more of the current generation of equipment to replace older versions of those same systems. Provided that assembly lines are still open, that approach allows DoD to avoid the costs of developing new systems, as it has done in continuing to procure F-15s, which were first produced in 1972. However, buying more of the current generation of equipment incurs the risk of not having what is needed to counter tomorrow's threats.

A fourth approach is to replace old equipment with a new generation of equipment that is more modern and technologically advanced. The services argue that that approach can reduce O&M costs because new generations of equipment are explicitly designed to reduce those costs. However, new systems often cost two to

three times more than the systems they replace, and the higher procurement costs are sometimes accompanied by higher O&M costs.²² Instead of reducing O&M costs, a new generation of systems could very well increase them. Examples of the next generation of equipment currently under development include the DD-21 Destroyer, Joint Strike Fighter, F-22 fighter, and Crusader self-propelled howitzer.

Even if the question of capability—a topic outside the scope of this analysis—is disregarded, choosing among the above approaches requires knowledge about three factors: how long equipment can be safely operated—its service life; what the O&M costs are for equipment at different ages; and whether rebuilding equipment effectively makes it “like new.” Although the services recognize that their knowledge of those factors is incomplete, an understanding of them is required for cost-effective decisionmaking.

Currently, DoD must choose among approaches for aging equipment on the basis of incomplete and fragmentary data. However, there are steps that the department could take to enable it to make more-informed decisions. To better understand the costs associated with age, DoD could collect data on the costs of operating and maintaining individual pieces of equipment that are similar except for age. In some cases, it could be worthwhile to identify the age or mileage of particular pieces of equipment in a unit and then to monitor the costs of the organizational-level, intermediate-level, and depot-level maintenance for each item over brief periods. Limiting the time period and focusing on particular units would reduce the effects of changes in accounting and maintenance policies, as well as problems in adjusting for inflation. The Army Materiel Systems Analysis Activity is employing this approach for Army equipment used by units at the National Training Center in Fort Irwin, California.

In addition, DoD could establish testing programs to track the costs of recently modified and unmodified systems in similar units and under similar operating conditions. Those programs would determine the cost-effectiveness of recapitalization programs. Although the Congress mandated in 1999 that DoD set up some testing programs to reduce O&M costs, those programs lack requirements to report estimated or actual savings and lack the methods of collecting data to determine their effectiveness.²³

22. Congressional Budget Office, *Paying for Military Readiness and Upkeep: Trends in O&M Spending* (January 1997).

23. Section 816 of the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999.

APPENDIX A: **MODELING OPERATION AND MAINTENANCE COSTS**

The Congressional Budget Office (CBO) analyzed three sets of data on operation and maintenance (O&M) costs for military aircraft using the RAND Corporation's 1990 model. Those analyses provide estimates of the effects of the average age of a particular type of aircraft on its O&M while taking into account the effects of other variables, including the pace of operations, the purchase price of the aircraft, and the calendar year. Each of those analyses indicates that an increase of one year in the average age of a fleet of aircraft increases O&M costs for that fleet by 1 percent to 3 percent above inflation. In two of the three data sets, the positive relationship between age and costs is statistically significant (that is, it is unlikely to be due entirely to chance). However, as explained below, whether those analyses are in fact capturing the effects of age on costs is unclear.

The RAND model used by CBO assumes that differences in the level of O&M costs for different types of aircraft are proportional to their purchase prices. CBO also made estimates using a more general model that allows for differences in the level of O&M costs for each type of aircraft that are independent of the purchase price. That approach, however, yields estimates of the effects of age on costs that are counterintuitive in that they are negative. Because the data do not distinguish between different models of the same basic type of aircraft, one explanation for that anomalous finding could be that the newest, most advanced versions of particular types of aircraft are the most costly to maintain. As a result, the introduction of new versions could lower the average age of a fleet while increasing its O&M costs. Data on the ages and O&M costs for individual aircraft—rather than the average ages and costs for different types of aircraft—may be required in order to develop credible estimates of the effects of age.

Data Used in the Analysis

CBO created three data sets using operating costs taken from two sources—the services' operation and support (O&S) databases and Historical Future Years Defense Program (FYDP) data that the services provided to the Office of the Secretary of Defense. CBO collected the data by aircraft type, or major design—such as the F-15, F/A-18, CH-53, and P-3.¹ The first and second data sets include costs collected by the Air Force Total Ownership Costs (AFTOC) database and the Navy's Visibility and Management of Operating and Support Costs (VAMOSC) database. Those databases include annual expenditures on O&M, personnel, and modification costs. The third data set uses the O&M portion of the costs for defense mission category 1

1. Variations within a type of aircraft, called mission design series—such as the F-15A and F-15B or the CH-53C and CH-53D—were not studied because either cost data were not specified to that level of detail, as was the case for the Air Force, or age was not, as was the case for the Navy.

(DMC1) from the FYDP data for different types of aircraft squadrons.² (Because the FYDP reports costs only for fighter, attack, bomber, and helicopter aircraft squadrons, and then only by major design, the regression analysis of these data is limited to those types of aircraft squadrons.)

Inventory, flying-hour, and age data for the Air Force are from the *Air Force Statistical Digest*. Such data for the Navy come from the Navy Center for Cost Analysis and Navy headquarters. Purchase prices, or procurement average unit costs (PAUCs), are from the Institute for Defense Analyses.

Estimates Based on the RAND Model

Pooling, or combining, different types of aircraft, CBO used regression analysis to estimate the relationship between an aircraft's characteristics and operating tempo and its O&M costs. The explanatory variables used in CBO's analysis include operating tempo, the aircraft's purchase price, the average age of the fleet of that type of aircraft, and the calendar year of the data. Operating tempo—measured as flying hours per aircraft—describes how much aircraft are used; CBO expected operating tempo to have a positive relationship with the costs of operating and maintaining the aircraft. Purchase price is used as a proxy for the different types of aircraft being pooled; CBO expected purchase price to have a positive relationship with O&M costs.³ Average age—measured in years—is the average age of the entire fleet of a type of aircraft in a given calendar year, divided by a hundred. Dummy variables for each calendar year are also in the model to capture the effects that annual budgets and changes in accounting policies or practices over time may have had on costs, independently of operating tempo, purchase price, or average age.

Using data for different calendar years and different types (major designs) of aircraft, CBO estimated the following equation:

$$\ln(\text{COST}) = \alpha + \beta_1 * \text{AGE} + \beta_2 * \ln(\text{TEMPO}) + \beta_3 * \ln(\text{PAUC}) + \beta_i * \text{Ydummies} + \epsilon$$

- 2. See Box 2 for a discussion of defense mission category 1 (DMC1).
- 3. The purchase price, or procurement average unit cost, is calculated by dividing the total procurement cost by the number of articles to be procured. The total procurement cost includes recurring and nonrecurring costs associated with the production of an item—such as costs for hardware and software, system engineering, engineering changes, and warranties—plus the costs of procuring technical data, training, support equipment, and initial spares. Because maintenance activities represent a kind of remanufacturing, one would expect operating costs for an aircraft fleet to vary with the purchase price. As aircraft become more expensive to purchase, the costs of spares, support equipment, and maintenance are also likely to increase.

Where:

COST	= operating costs/inventory
α	= intercept term
AGE	= average annual age/100
TEMPO	= annual flying hours/inventory
PAUC	= procurement average unit cost
Ydummies	= dummy variables for years

The coefficient β_1 indicates the percentage change in costs per aircraft when the average age of the fleet increases by one year, all other things being equal. The coefficients β_2 and β_3 are elasticities that indicate the percentage change in costs per aircraft when there is a 1 percent change in the relevant explanatory variable, with the other variables held constant. The β_i coefficients capture the effects of different calendar years on costs. In this model, the effect of a particular explanatory variable on costs depends on the values of the other explanatory variables.

AFTOC Data on the Air Force's Aircraft. CBO compiled 68 observations using data on O&S expenditures from the Air Force's AFTOC database. That database, which covers 1996 through 1999, includes 17 active fighter, attack, bomber, cargo, and helicopter aircraft. The regression results are as follows:

$$\ln(\text{COST}) = 4.0 + 0.98 \text{AGE} + 0.58 \ln(\text{TEMPO}) + 0.43 \ln(\text{PAUC}) + \beta_i * \text{Ydummies}$$

T-stat	(4.367)	(1.612)	(5.466)	(10.080)	R ² : 0.73
P-value	(0.0001)	(0.1121)	(0.0001)	(0.0001)	F: 27.015

A P-value of less than 0.01 indicates that, with 99 percent confidence, the related variable does have an effect on cost.

VAMOSC Data on the Navy's Aircraft. CBO compiled 164 observations using data on O&S expenditures from the Navy's VAMOSC database. That database, which covers 1986 through 1999, includes 13 fighter, attack, cargo, and helicopter aircraft. The regression results are as follows:

$$\ln(\text{COST}) = 2.78 + 2.38 \text{AGE} + 0.74 \ln(\text{TEMPO}) + 0.19 \ln(\text{PAUC}) + \beta_i * \text{Ydummies}$$

T-stat	(5.572)	(4.549)	(8.071)	(4.273)	R ² : 0.51
P-value	(0.0001)	(0.0001)	(0.0001)	(0.0001)	F: 9.50

FYDP Data on Air Force and Navy Aircraft. CBO compiled 327 observations using data on O&M expenditures from the FYDP database. That database, which covers 1976 through 1999, includes 20 active Air Force and Navy fighters, bombers, and attack aircraft. The regression results are as follows:

$$\ln(\text{COST}) = -1.97 + 2.50 \text{AGE} + 0.62 \ln(\text{TEMPO}) + 0.72 \ln(\text{PAUC}) + \beta_i * \text{Ydummies}$$

T-stat	(-6.365)	(4.970)	(5.044)	(17.231)	R ² : 0.55
P-value	(0.0001)	(0.0001)	(0.0001)	(0.0001)	F: 14.16

Findings. Two of the analyses—those using VAMOSC data on Navy aircraft and FYDP data on Air Force and Navy aircraft—reveal a significant positive relationship between age and operating costs: an additional year of average age is associated with an increase in O&M costs of 1 percent to 3 percent per year. (The other analysis—that using AFTOC data on Air Force aircraft—also describes a positive relationship between age and costs, but the small number of observations limits the certainty of the result.) Those findings suggest that (with operating tempo, purchase price, and calendar year controlled for) the effects of aging—fatigue, corrosion, and obsolescence—may be showing up in O&M costs, as reflected in the services' databases and the Department of Defense's FYDP data.

All three sets of data reflect a positive relationship between operating costs and purchase price, suggesting that the higher the purchase price, the higher the O&M costs.

All three sets of data describe a positive relationship between operating costs and the pace of operations, or operating tempo. As flying hours increase, so do many supporting activities, including the use of fuel, spares, maintenance materials, and support equipment. Hence, operating tempo is positively associated with costs.

The dummy variables for calendar year were insignificant in all three sets of data.

Estimates Based on a More General Model

The model used in the above analyses assumes that an increase of one year in the average age of the fleet of a particular type of aircraft boosts O&M costs by the same percentage, regardless of the type of aircraft. That assumption is essential if the data for different types of aircraft are to be pooled and used to derive a single estimate of the effects of age. Another assumption underlying the above model is that differences in the level of O&M costs for different types of aircraft are proportional to the price of the aircraft.

In an alternative model, CBO relaxed that second assumption by introducing separate dummy variables for the different types of aircraft:

$$\ln(\text{COST}) = \alpha + \beta_1 * \text{AGE} + \beta_2 * \ln(\text{TEMPO}) + \beta_i * \text{Ydummies} + \beta_j * \text{MDSdummies} + \epsilon$$

Where:

Ydummies	= Dummy variables for years
MDSdummies	= Dummy variables for types of aircraft

For all three sets of data, CBO compared the first, restricted model with the second, more generalized one using a standard *F* test. In each case, and with 99 percent confidence, CBO found that the second model was more appropriate. In other words, there are differences among the O&M costs of different fleets of aircraft that are not captured by the purchase price.

However, estimates of the effects of age on costs made using this more general model are counterintuitive: reductions in the average age of a fleet appear to be associated with an increase in O&M costs. One explanation could be that newer versions of some types of aircraft are more costly to maintain. If so, purchasing those versions would result in both a reduction in the average age of the fleet and an increase in O&M costs. For example, as newer versions of the F-15 (the C and D versions) enter the inventory, the average age of the F-15 fleet declines, but advanced avionics and modifications may make the newer aircraft more expensive to maintain than older versions of the F-15.

That last finding highlights the need for analyses based on the age and O&M costs for individual aircraft, rather than on the average ages and costs for fleets of different kinds of aircraft.

APPENDIX B:
BIBLIOGRAPHY OF CITED STUDIES ON AGING AIRCRAFT

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